THE EFFECTS OF GROUND-PLANE OF A TEXTILE HIGHER MODE MICROSTRIP PATCH ANTENNA ON SAR

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Project Acronym:	**SERENE**
Project Full Title:	**S**tudy of the human **E**xposure to elect**R**omagnetic fi**E**lds of wearable a**N**t**E**nnas

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BIOGRAPHY

Maria Seimeni received a 5-year Diploma from the ECE School of Democritus University of Thrace (DUTh), her M.Sc in Systems Engineering in Aeronautics from Politecnico di Torino (PoliTo), her PhD in Telecommunications from the ECE School of National Technical University of Athens (NTUA), while she serves as a PostDoctoral Research Fellow at the National Centre for Scientific Research"Demokritos" since 2017.

Since 2007, she has worked for System Integrators - that operate through Space and Defence Aerospace business segments – and SMEs acting under the roles of: (i) EMC Systems Engineer and/or Project Manager; (ii) a Tests Engineer; (iii) a Tests Manager/Supervisor, (iv) Technical Manager; (v) RF Team Leader; (vi) Key SW EMC Systems Engineer (vii) Wireless Communications Engineer, (viii) Antenna Engineer. She's also been affiliated with the NTUA (ICBNet Lab, MFOLab) since 2012. Maria Seimeni is also a reviewer in peer-reviewed Scientific Journals (IEEE Communications Letters, ETT, IET Communication, IET Microwaves-Antennas Propagation, IET Electronics Letters, IET Science,Measurement&Technology) and Scientific Conferences (iWAT, EUCAP, LAPC, WTS).

Dr. Seimeni's expertise is related to four main pillars. She has a background in μWaves Circuit Design and EMC Systems Engineering. During her PhD on Wireless Communications, she was dealing with MIMO antennas, multi-RATs (radio access terminals) multi-cellular networks and the bridging of the heterogeneous ones at MAC and PHY layers. Wearable Antennas are the focal point of her PostDoc activities.

ABSTRACT

This work studies the human exposure to EMFs that are generated by textile microstrip patch antenna and proposes a generalized methodology to reduce it. First, an antenna -commonly used for wearable applications- that highly interacts with the human body is investigated. To reduce exposure, the radiation directed onto the body is controlled by resizing the ground-plane. Despite this modification, the antenna maintains acceptable performance, its low profile, and low material and fabrication costs. Simulations show that as the ground-plane increases: (i) back radiation is mitigated leading to significant SAR reduction; (ii) the antenna interacts less with the human phantom and demonstrates acceptable performance. As the antenna under investigation is a typical one for body-centric communications and the ground-plane resize is a simple procedure, the proposed methodology may be applied to a vast variety of wearable applications.

Index Terms: Textile Antennas, Ground Plane, Human Exposure Mitigation

HUMAN EXPOSURE METRICS AT 2.4 GHZ **[1/2]**: SPECIFIC ABSORPTION RATE (SAR)

A measure of the rate of energy absorbed by (dissipated in) an incremental mass contained in a volume element of dielectric materials (i.e. Biological tissues).

SAR units are **W/kg** or **mW/kg**

Guidelines for human exposure to RF fields are based on SAR thresholds where adverse biological effects may occur. When the human body is exposed to an RF field, the SAR experienced is proportional to the squared value of the electric field strength induced in the body.

$$SAR = \frac{\sigma |E|^2}{\rho}$$

σ	electrical conductivity of the biological tissue
E	the rms of the Electric Field Strength
ρ	the density of the biological tissue

HUMAN EXPOSURE METRICS AT 2.4 GHZ **[2/2]**: SPECIFIC ABSORPTION RATE (SAR)

Given the uncertainty of the effects posed by EM fields, pre-cautionary principles of the maximum permissible levels of EM radiation on human bodies are included in countries' regulations.

Specific **A**bsorption **R**ate safety limits:

- are internationally standardized by:-
  - ► ICNIRP Guidelines (**2W/Kg** over **10gr** of tissue)
  - ► IEEE Standard (**1,6W/Kg** over **1gr** of tissue)

- depends on:-
  - ► Operating Frequency
  - ► Intensity of the field
  - ► Position/Distance of the Body (e.g. Near- or Far- Field)
  - ► Characteristics (electrical properties) of the exposed body

SPECIFIC ABSORPTION RATE CONTROL MECHANISMS

Methods	Mechanism	SAR Reduction (%)
Control of the direction of the radiation to weaken radiation towards the human body	Parasitic element	~ 30
	Wavetraps	~ 30
	Slots	~ 40
	Control antenna pattern using dividing feed	~ 90
Shield EMFs against human body and vice versa	Reflecting elements	~ 70 - 80
	Ferrite loading	~ 57
	Electric conductor	~ 50
	Metamaterials	~ 75

M. A. Seimeni et al., "Mitigation Of End-User's Exposure To EMF Of Wearable Antennas Through Ground-Plane Interventions," The Loughborough Antennas & Propagation Conference (LAPC 2018), Loughborough, 2018, pp. 1-6.

ANTENNA SELECTION

The antenna under investigation should demonstrate attributes that:

- *affect exposure levels.*
  Orientation of polarization relative to the body is one of the parameters that primarily affects the exposure levels. ➔ **Polarization Normal to the Body** (excitation at mode higher than its fundamental)

- *are suitable for wearable applications.*
  Low profile, unobtrusiveness, low material and fabrication costs. ➔ Textile Microstrip Patch Antenna

Wearable Textile Higher Mode Microstrip Patch Antenna (HMMPA) is designed at **2.4 GHz.**

A. Paraskevopoulos et al., "Higher-Mode Textile Patch Antenna With Embroidered Vias For On-Body Communication," in IET Microwaves, Antennas & Propagation, vol. 10, no. 7, pp. 802-807, 15 5 2016.

HUMAN-EQUIVALENT PHANTOM SELECTION

- Ease of design (reasonable computational and shape complexity);
- Ease of fabrication (including fabrication costs);
- Ease of reproducibility;
- Ease to control and retain its electric properties;
- High EM equivalency with the part of the human body of interest.

2/3 Muscle-equivalent Homogeneous Rectangular Phantom

Gabriel C., "Compilation of the Dielectric Properties of Body Tissues at RF and Microwave Frequencies", Brooks Air-Force Base, report no. AL/OE-TR-1996-0037.

EM SIMULATION SET-UPS: THREE SCENARIOS [1/4]

Scenario Title	Scenario Description
Free Space	Antenna in Free Space
Reference Scenario	Antenna on Human Phantom
Test Scenario	Modified Antenna (resized ground-plane) in Free Space and on Human Phantom

CST Studio Suite. https://www.3ds.com/products-services/simulia/products/cst-studio-suite/solvers/

EM SIMULATION SET-UPS: THREE SCENARIOS [2/4]
FREE SPACE SCENARIO: HMMPA (AM0) DESIGN

Parameter	Value (mm)
Lg = Wg	50
Wfelt	50
W	26.9
W_f	4.2
Df	1.3
hs,1	2.9
hs,2	1.1
h_t	0.13
Fi	25
Dy	1
Dvias	4

Table I: Wearable patch antenna geometry

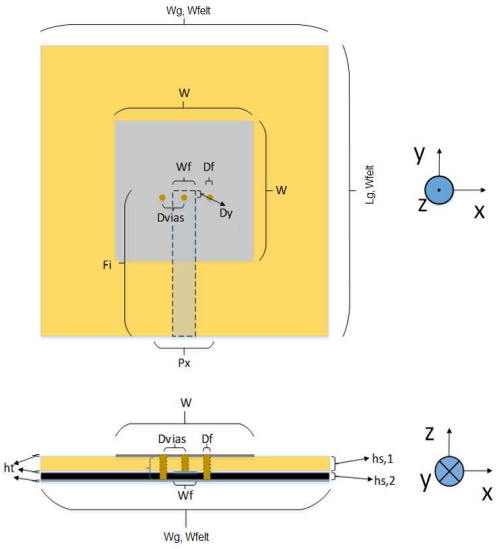
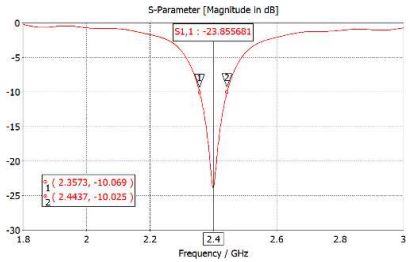


Fig. 1: Top- and Bottom-views of the HMMPA

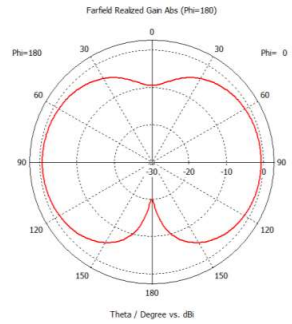
Material	Properties	Antenna Parts/Layers
NoraDell	$\sigma = 1.54*10^6$ S/m	Ground-plane, radiating patch, microstrip feedline
Felt 1	$\varepsilon r1 = 1.23$, $\tan\delta 1 = 0.022$	Substrate 1
Felt 2	$\varepsilon r2 = 1.23$, $\tan\delta 2 = 0.022$	Substrate 2
Copper	$\sigma = 5.8 * 10^6$ S/m	Ground Vias and Feed Vias

Table II: Antenna Materials and Properties

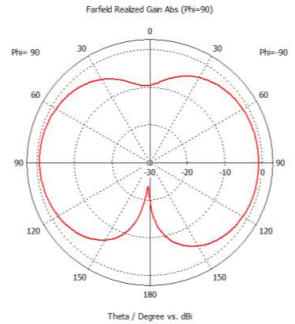
Simulated S11



Free Space Radiation Patterns



(a) x-z plane



(b) y-z plane

EM SIMULATION SET-UPS: THREE SCENARIOS [3/4]
REFERENCE SCENARIO: HMMPA (AM0) ON HUMAN PHANTOM

SAR^*_o = 0.6046 W/kgr

λ/10,…,10*(λ/10) increments

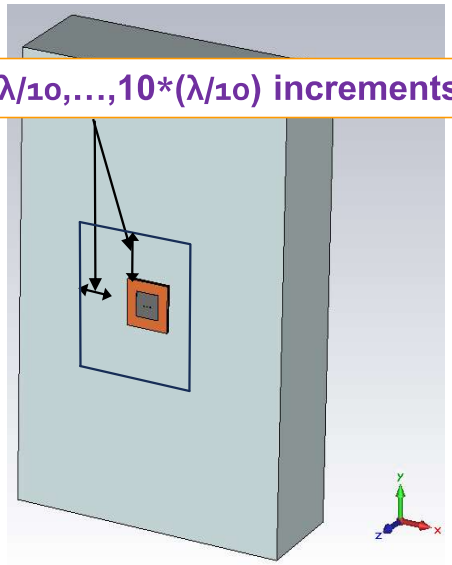
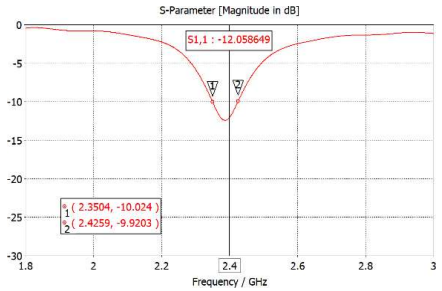


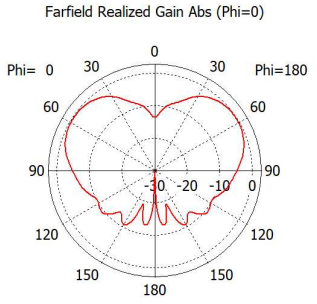
Fig. 2: HMMPA on human phantom [L = 32.2cm, H = 48.42cm, W = 11.2cm]

A constant accepted power (0,5 Watt) is assumed in order to compare all SAR results on a common basis

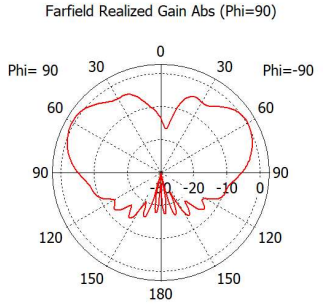
Simulated S11



Radiation Patterns



(a) x-z plane



(b) y-z plane

EM SIMULATION SET-UPS: THREE SCENARIOS [4/4]
TEST SCENARIO: RESIZED GROUND-PLANE

Free Space (AM0, AM1,…, AM10)

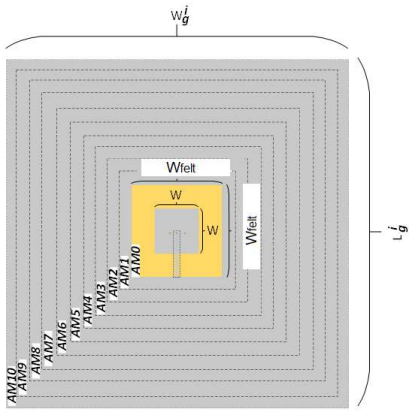
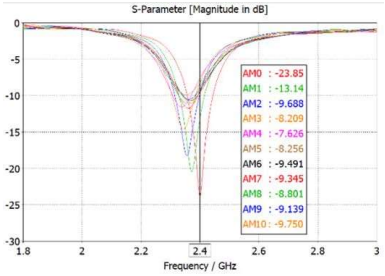
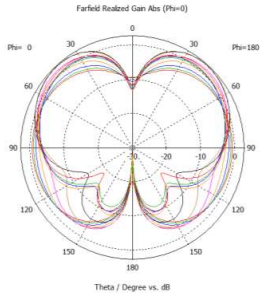


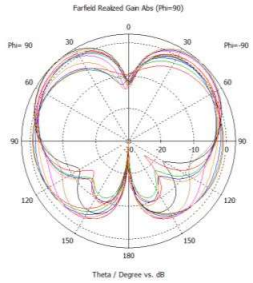
Fig. 3: HMMPA (AM0) and AM1 to AM10 in free space.

Simulated S11





(a) x-z plane



(b) y-z plane

With Human Phantom (AM0, AM1,…, AM10)

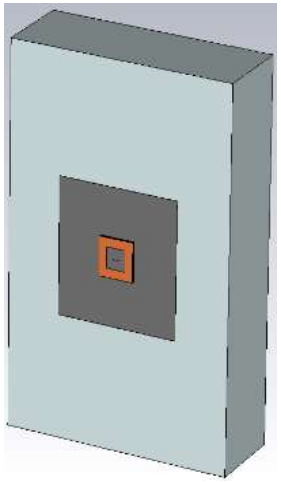
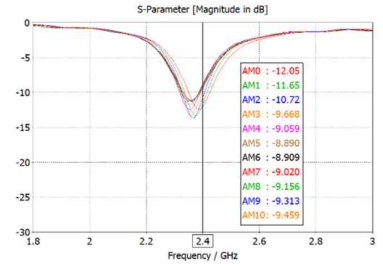
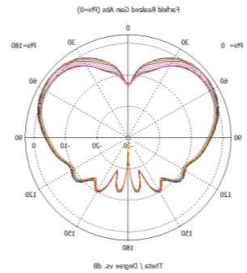


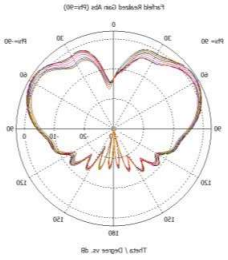
Fig. 4: Example with AM10 on human phantom.

Simulated S11





(a) x-z plane



(b) y-z plane

DISCUSSION ON SIMULATIONS

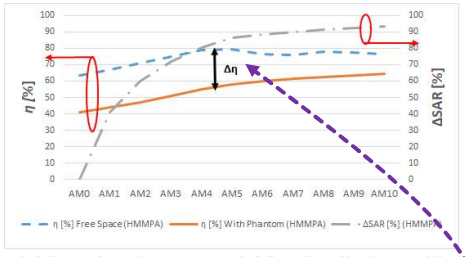


Fig. 5: SAR reduction w.r.t. SAR_o. Radiation efficiency in free space and with phantom.

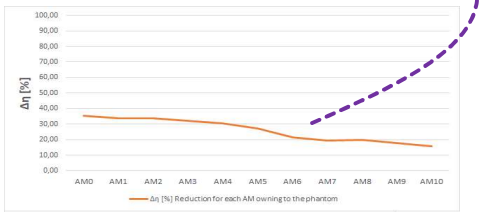


Fig. 6: Phantom impact [%] on the efficiency of each AM_{HMMPA}s.

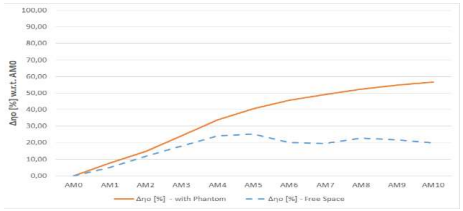


Fig. 7: HMMPA radiation efficiency enhancement of the AMs w.r.t. η_{AM0} versus ground-plane increase (free space, with phantom).

As the ground-plane increases:-

- **the antenna radiation efficiency (η) enhances (free space, with phantom). (Fig. 5). This is also confirmed by Fig.7, where the efficiency of each antenna model (AM1-AM10) is compared to the AM0.**
- the interaction between the antenna and the human body is decreased (also confirmed by Fig.6)

$$\Delta\eta_j = \frac{\eta_j^{fs} - \eta_j^{ph}}{\eta_j^{fs}} * 100 \ [\%];\ j = 0, \dots, 10$$

- **SAR reduction can reach the 93.2%. (Fig. 5)**

$$\Delta SAR_j = \frac{SAR_o - SAR_j}{SAR_o} * 100 \ [\%];\ j = 0, \dots, 10$$

In Fig. 5, there is a big difference ($\Delta\eta$) between the radiation efficiency in free space and that with phantom for each AM_i.

$$\Delta\eta o_j^{fs} = \frac{\eta_o^{fs} - \eta_j^{fs}}{\eta_o^{fs}} * 100 \ [\%];\ j = 0, \dots, 10$$

$$\Delta\eta o_j^{ph} = \frac{\eta_o^{ph} - \eta_j^{ph}}{\eta_o^{ph}} * 100 \ [\%];\ j = 0, \dots, 10$$

CONCLUSIONS

Through ground-plane increase, **HMMPAs** (antennas with performance sensitive to the presence of the human body) may jointly:-

(i) **ensure acceptable performance and maintain low profile, as well as material and fabrication costs** and
(ii) **significantly reduce SAR values.**

Technique's simplicity and the antenna type –typical of wearables technology- support the claim of generality of the proposed method for a vast variety of wearable wireless communication systems that operate on the human body.

REFERENCES

- W. G. Scanlon and N. E. Evans, "Numerical Analysis Of Bodyworn UHF Antenna Systems," in Electronics & Communication Engineering Journal, vol. 13, no. 2, pp. 53-64, April 2001.
- T. Wu, T. S. Rappaport and C. M. Collins, "Safe for Generations to Come: Considerations of Safety for Millimeter Waves in Wireless Communications," in IEEE Microwave Magazine, vol. 16, no. 2, pp. 65-84, March 2015.
- A. Paraskevopoulos, D. d. S. Fonseca, R. D. Seager et al., "Higher-Mode Textile Patch Antenna With Embroidered Vias For On-Body Communication," in IET Microwaves, Antennas & Propagation, vol. 10, no. 7, pp. 802-807, 15 5 2016.
- J. Ryckaert, P. De Doncker, R. Meys et al., "Channel Model For Wireless Communication Around Human Body," in Electronics Letters, vol. 40, no. 9, pp. 543-544, 29 April 2004.
- CST Studio Suite. https://www.3ds.com/products-services/simulia/products/cst-studio-suite/solvers/
- Thomas Weiland, “A discretization method for the solution of Maxwell’s equations for six-component fields,” Electronics and Communications AEU, Vol. 31, No. 3, 116–120, 1977.
- Gabriel C., "Compilation of the Dielectric Properties of Body Tissues at RF and Microwave Frequencies", Brooks Air-Force Base, report no. AL/OE-TR-1996-0037.
- M. A. Seimeni, A. Tsolis, A. A. Alexandridis et al., "Mitigation Of End-User's Exposure To EMF Of Wearable Antennas Through Ground-Plane Interventions," The Loughborough Antennas & Propagation Conference (LAPC 2018), Loughborough, 2018, pp. 1-6.
- 3GPP TR 38.912, “Study on new radio access technology,” V14.1.0, August 2017. Available online: http://www.3gpp.org/ftp//Specs/archive/38_series/38.912/38912-e10.zip, accessed 22 July 2019.

"*SERENE*" PROJECT AT A GLANCE

Motivated by the public concern about the hazardous effects that the antennas of wearable devices potentially cause to the human tissues, this project aims to address this challenge by investigating and proposing methods to reduce the electromagnetic (EM) field radiation of the wearable antennas to the direction of the user's body. This study primarily includes antenna design techniques and methods to reduce the absorbed power by the human body and therefore well-drive down the Specific Absorption Rate (SAR). The proposed wearable antenna models are examined and evaluated through a measuring procedure that is developed for this purpose. Proper measuring setups and phantoms simulating the EM behavior of human body are also developed.

Singular Logic

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